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Coronal index of solar activity and cosmic ray intensity variations

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Abstract . Sunspot numbers, a reliable parameter of solar activity, is generally used in cosmic ray modulation studies Besides sunspot number, many other solar indices such as grouped solar flares coronal holes area have been used to study their relationship with cosmic ray intensity However R_z, a indicator of solar activity, does not propagate in the interplanetary medium. Therefore, we have used a new index *viz* coronal index (CI) in cosmic ray modulation studies CI is a full disk solar index and it may be calculated from ground-based patrol observations of the solar corona This analysis indicates that the CI would be a better suited parameter for such studies

Keywords Cosmic rays, coronal Index, solar activity.

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1. Introduction

The solar activity as measured by sunspot numbers, shows inverse correlation with cosmic ray intensity. Besides the sunspot number, many other solar indices have been used to study their relationship with cosmic ray modulation. As we know, generally grouped solar flares, solar radio flux (2800 MHz), area of coronal holes and tilt angle have been used as effective solar indices. All these indices are highly correlated with each other and each of them can serve the purpose to show their association with cosmic rays [1,2,3]. Shukla *et al* [4] and Singh *et al* [5] have made an attempt to use the tilt angle as solar parameter in cosmic ray studies. They have reported significant negative correlation between cosmic rays and tilt angle (α). In the present study, we have taken sunspot number (R_z), grouped solar flares (GSF) and coronal index of solar activity (CI) to investigate their relationship with cosmic rays time variation. The coronal index data are taken first time to observe their associationship with long-term cosmic ray intensity variation. The results obtained in this study, confirm coronal index as a reliable solar parameter, which may be used in cosmic ray time variation studies.

The index should help us to understand the role of solar activity in long-term cosmic ray modulation. It will also be useful to express the solar activity in a quantitative way, the pattern of evolution of active region as regards shorter intervals and the solar activity cycle pattern as regards longer intervals. In preview to it, we attempt to derive and explain the relationship of coronal index of solar activity with cosmic ray intensity variation.

2. Data and method of analysis

In this analysis, we have taken the monthly mean values of coronal index (CI) of solar activity from the Solar Geophysical Data comprehensive Reports [6]. The coronal index is the average daily power (irradiance) emitted in the green coronal line from the entire solar corona as observed from the earth into steradian towards earth [7].

The intensity of green corona line (Fex XIV, 5303 Å) is routinely measured at several coronal station around the world. Each set of measurement includes a series of limb observations with a log of 5° in the positional angle, beginning from the north solar pole (0°) and proceeding counter clockwise around the solar disk (*e.g.* 90° is E 90, 270° is W 90). These data sets from measurements are used for calculating the coronal index of solar activity. Here

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computation of the energy radiated in line 5303 Å is briefly given below

The energy radiated from the corona in front of the disk contribute to the total energy. The energy radiated from above the limb, E_2, is determined from the intensity observed at a high of 40" and from the known gradient by integrating over the hemisphere turned towards the earth. We obtained the energy E_{II} so with addition of 1/2 E_I, we can get total energy E radiated by the corona

$$E = E_{II} + 1/2\, E_I$$

By adopting the various mathematical process, Rybansky [7] obtained the values of E_{II} and E_I. In computing the values of E_{II} and E_I, he arrived at an intermediate result which may be useful in analysing the solar activity cycle in various coronal attitudes. For each latitude and observational day we obtained the number $1/2 \sum_i (\theta_{i+1} - \theta_i)(I_{0,i} + I_{0,i+1})$. If this number is divided by 180, we arrive at the average intensity of the line 5303 Å at latitude b for the given day given by

$$I_{0,b} = 1/360 \sum_i (\theta_{i+1} - \theta_i)(I_{0,i} + I_{0,i+1})$$

where I_0 is the intensity observed in coronal units 40" above the solar limb.

The average intensity $I_{0,b}$ can be used for studing the solar activity cycle at various coronal latitudes.

3. Results and discussion

Generally sunspot numbers are used as one of the reliable and easily available solar parameters to measure solar activity. However no reliable parameter is established to study the relationship between solar activity and cosmic rays [8,9]. Nevertheless, recently a number of solar features were identified and studied in association to cosmic ray modulation [3,8,10].

Some of these solar features such as grouped solar flares, tilt angle, coronal mass ejections and coronal green lines were considered on the basis of their expected physical mechanism, without making effort to find out, whether these parameters by themselves are correlated with each other or not. Therefore, it has been necessary to search for a new reliable solar parameter, which has direct influence on interplanetary medium and also shows high positive correlation with another solar parameters.

Shrivastava *et al* [10] have earlier reported that the magnitude of 2800 MHz solar radio flux is a measure of solar activity and is highly correlated with the sunspot number. Other solar parameters such as area of solar polar coronal holes and coronal mass ejections are also found well-correlated/anti-correlated with the sunspot number, and hence, except for their physical mechanism (if any), the sunspot numbers would fully serve the purpose. Recently in 1997, Singh *et al* [5] reported the association of waviness of Heliospheric neutral current sheet (tilt angle α) with cosmic ray intensity. The tilt angle α has been derived to assess their suitability for the analysis of the long-term variation of cosmic ray intensity.

In this work, we have used a coronal index (CI) of solar activity in addition to sunspot number (R_Z) and grouped solar flares (GSF). The CI reflects both the daily changes in the strong local photospheric magnetic fields as well as presence of long-lived (3–6 months) coronal structures. Coronal index as a full disk solar index is very easily comparable with solar indices that arise under different physical conditions.

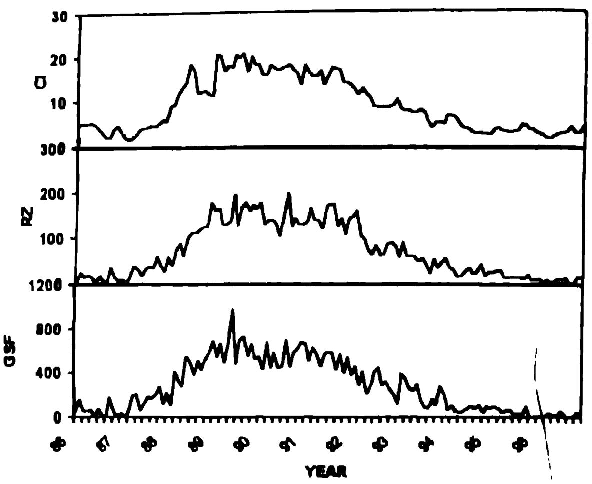

Figure 1. The monthly mean values of grouped solar flares (GSF), sunspot numbers (R_z) and coronal index (CI) for the period of 1986 to 1996

Monthly mean values of three solar indices (R_z, GSF and CI) are plotted in Figure 1 for the interval of 1986 to 1996, covering the solar sunspot cycle 22. The figure shows the eleven year cyclic patterns for all the three solar indices (GSF, Rz and CI), in which the trend of similar variational patterns for Rz and CI can be observed. Figure 2 shows the

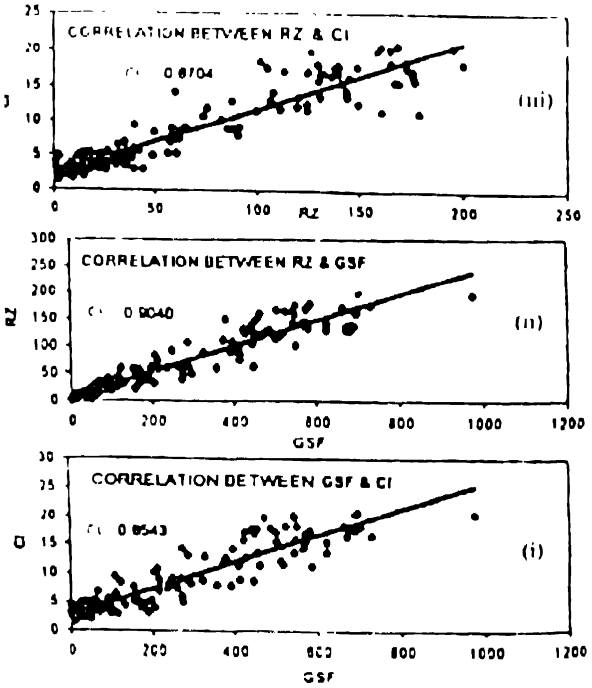

Figure 2. The correlation plots of (i) CI *vs* GSF (ii) R_z *vs* GSF and (iii) CI *vs* R_z. Regression lines are shown in all the three plots for the interval of 1986 to 1996

three blocks of correlation results among these three solar indices (R_z, GSF and CI). Upper block shows the correlation between the monthly mean values of R_z and CI along with regression line and the value of correlation coefficient which is 0.87. Middle and lower blocks show correlations between R_z and GSF and GSF and CI respectively. The correlation coefficients are 0.90 and 0.85 respectively. Results obtained from Figure 2, shows significant positive and high correlation of coronal index (CI) with grouped solar flares (GSF) and sunspot numbers (R_z). Hence, it proves the reliability of

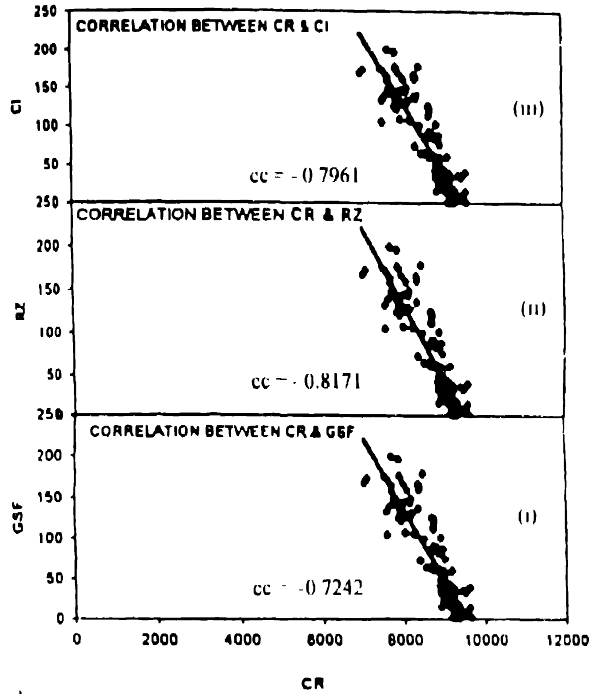

Figure 3. Correlation's points are shown for (i) GSF vs CR (ii) R_z vs CR and (iii) CI vs CR for the period of 1986 to 1996. Values of correlation coefficients (cc) and regression lines are given in all the three blocks.

coronal index as another solar parameter. Correlation of cosmic ray intensity (CR) with these three solar indices are plotted in Figure 3, for the interval 1986 to 1996. The correlation coefficients obtained from CI vs CR are almost similar to that of R_z vs CR. The correlation coefficient in each case, as well as regression lines, have been calculated and are depicted in Figure 3. The monochromatic corona, is quite variable in its intensity, mainly above active photospheric regions and in the vinicity of active prominences. Short-term changes in solar corona can cause different results at different stations, even if the data were obtained by the same method and photometry done on same day.

Coronal index which we use in this cosmic rays modulation study are mostly derived from the manifestations of the activity in the photosphere and the cromosphere *i.e.* from sunspot, flares, facular and floccular fields *etc*. The proposed coronal index of solar activity is expressed in terms of the energy emitted by the whole corona in the line 5303 Å into one steradian towards the earth. Unified data from all coronal stations situated on different parts of earth were used.

The CI is a full disk solar index and we can compare it with other solar indices. The substantial advantage of CI is the fact that it may be calculated from ground based petrol observations of the solar corona. As we get high positive correlation between CI and R_z, it may be possible to use CI as reliable solar activity index in cosmic ray modulation studies. It is theoretically found that the use of coronal index on cosmic ray modulation studies is reasonable due to its direct influence in the heliospheric region. Further, we can see that the sunspot numbers represent only photospheric regions of Sun, on the other hand CI reflects the whole corona and its continuous radiating energy towards the earth surface. The components of coronal index such as solar flares, coronal mass ejections (CME), facular and sunspots are responsible for propagation of energy into interplanetary medium, which turn into modulation of cosmic ray particles. From the geophysical point of view, the coronal index is intended as an aid to elucidate solar-terrestrial relationship.

From the results presented here, it is therefore concluded that the coronal index of solar activity should be adopted in further studies in the area of cosmic ray modulation as well as in the area of solar terrestrial physics.

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